Traumatic Pseudoaneurysm of the Distal Anterior Cerebral Artery Following Penetrating Brain Injury Caused by a Crossbow Bolt: A Case Report

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Introduction

Penetrating brain injury (PBI) is relatively rare in Japan. While more than 30 cases of PBI have been reported in Japan, with causes including nail-gun, chopsticks, umbrella, and tree branches, PBI caused by crossbows has not been reported. While more than 30 cases of PBI have been reported in Japan, approximately 1% of all intracranial aneurysms. Globally, 15 case reports of PBI by crossbow bolts have been published, of which only one involved delayed formation of TICA.

We describe herein a case of PBI caused by a crossbow bolt in which pseudoaneurysm appeared late in the distal anterior cerebral artery (ACA) and was successfully treated surgically.

Case Report

The patient was a 25-year-old man who was taking antidepressants for major depression. He discharged a crossbow into his head in a suicide attempt, and was witnessed walking outdoors 5 hrs after the attempt. On presentation, level of consciousness was E4V5M6 according to the Glasgow Coma Scale, and no significant neurological deficits were apparent.

The crossbow bolt had penetrated the head from the right pterion to the left temporal region (Figs. 1A and 1B), with the fletchings buried in the entry site. After cutting off the tip of the crossbow bolt, computed tomography (CT) of the head was performed. The crossbow bolt had passed nearly the pericallosal artery, and 3D rotational angiography revealed that the bolt had barely missed the pericallosal artery (Figs. 1C and 1D). After administration of cefazolin, the patient was promptly taken to the operation room for removal of the crossbow bolt.

A bicoronal skin incision with borders including the entry and exit sites of the bolt was created. Prior to the craniotomy, the fletchings buried in the skin were removed. After bifrontal craniotomy, the crossbow bolt was extracted from the exit site while confirming on intraoperative ultrasonography that hematoma adjacent to the tract was not increasing. The bone flap was discarded because of the risk of contamination. The operative field was copiously irrigated, and a subdural intracranial pressure sensor was inserted to detect delayed expansion of the hematoma.

No postoperative expansion of the hematoma was identified. The patient did not show any paralysis, paresthesia, or cognitive dysfunction. Cefazolin was administered for 1 week postoperatively, and no infection occurred. Follow-up CT/CT angiography (CTA) of the head was performed on postoperative day (POD) 1, 8 (Figs. 2A and 2B), and 15. The hematoma gradually disappeared, but the irregularity of the vascular wall was observed at the bifurcation of the pericallosal artery and right posterior internal frontal artery (PIFA). No change in size from POD1 to 15 was identified, but head CTA performed on POD35 showed a 4 mm aneurysm at the bifurcation (Fig. 2C). Catheter angiography showed contrast

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Received: April 6, 2017; Accepted: June 15, 2017

Online November 24, 2017

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medium pooling in the aneurysm, indicating pseudoaneurysm formation (Fig. 2D). Trapping of the pseudoaneurysm and right PIFA-left cortical branch side-to-side bypass surgery was performed on POD38.

We observed the right PIFA via a right interhemispheric approach. After right PIFA-left cortical branch bypass, the aneurysm was trapped and resected (Figs. 3A and 3C). Elastica van Gieson staining of the specimen revealed a lack of internal elastic lamina, confirming the diagnosis of pseudoaneurysm (Fig. 3D).

Postoperative angiography showed anterograde flow through the right PIFA-left cortical branch bypass (Fig. 3B), and N-isopropyl-p-[123I] iodoamphetamine single-photon emission CT showed no reduction of flow in the right medial frontal lobe. Diffusion-weighted imaging showed no infarction in the right medial frontal lobe, and parenchymal damage was limited to the path of the crossbow bolt in a fluid-attenuated inversion recovery imaging (Figs. 4A and 4B).

Nineteen days after surgery, the patient was transferred to a rehabilitation facility. Cranioplasty was performed 3 months after the initial decompressive craniectomy. Eight months after injury, no neurological deficit or cognitive dysfunction has been identified.

**Discussion**

Compared to firearm projectiles, an aluminum crossbow bolt with a conical head has a relatively low velocity (up to 58 m/s), but the sharpness and kinetic energy are still sufficient...
to cause penetrating skull injuries. The major risk is that of
direct injury to the cerebral parenchyma, and vascular injury
is sometimes revealed on removal of the foreign body.\(^1\)

The mechanism of penetration for an arrow or bolt is dis-
tinct from that of a bullet. Because of the sharp force applied
by the bolt, injury is limited to tissues directly in the path of
the arrowhead.\(^2\) The shaft of the bolt in situ can exert pres-
sure on the wound, functioning as an incomplete tamponade,
because the tip of a sports arrow is basically the same diam-
eter as the shaft.\(^3\) In our patient, intraparenchymal hematoma
was therefore limited to the path of the crossbow bolt.

As shown on 3D rotational angiography (3DRA) (Fig. 1D),
the crossbow bolt and origin of the PIFA were separate from
each other. A small prominence is recognizable at the origin
of the PIFA on 3DRA, indicating that the prominence was
formed by forceful stretching of the falx cerebri. We specu-
late that this traumatic aneurysm appeared as a result of
indirect mechanical injury, which has occasionally been
reported in the past.\(^4-6\)

Current surgical management of PBI clearly tends toward
minimizing the degree of debridement. No controlled studies
have evaluated the relative efficacy of various degrees of
debridement in preventing infection and minimizing the
development of seizure disorders. Gonul et al.\(^7\) retrospec-
tively reviewed 148 patients whose penetrating brain injuries
were locally debrided and the dura tightly closed without
attempts to remove deeper fragments of bone or metal. They
reported a discharge mortality rate of 8% and an infection or
craniectomy) to minimize complications remains uncertain.
Generally recommended procedures are as follows: debride-
ment of necrotic brain tissue; removal of accessible bone or
foreign body fragments, only when the neurological risk is
not increased; removal of intracranial hematomas exerting
significant mass effects; and watertight closure of dural
defects.\(^7\)

In our case, the tip of the crossbow bolt was cut off and
the shape of the cross-section was irregular and sharp. For
this reason, the crossbow bolt was extracted from entrance...
Fig. 3  (A, B) Illustration demonstrating trapping with the right posterior internal frontal artery (PIFA)-left cortical branch side-to-side bypass and postoperative three-dimensional rotational angiography (3DRA) of the right internal carotid artery (asterisk: aneurysm; arrow: pericallosal artery; small arrow: right PIFA; arrowhead: left cortical branch). Successful revascularization with the bypass is seen on 3DRA. (C) Intraoperative view of the pericallosal artery (arrow), PIFA (small arrow) and pseudoaneurysm (asterisk). (D) Elastica van Gieson stain of the resected specimen (magnification, 40x) shows no internal elastic lamina (arrow; aneurysm lumen).

to exit, so that the cross-section did not come into contact with brain tissue. Also, since the crossbow bolt had passed near the ACA, intraoperative ultrasonography was useful in confirming the absence of active bleeding at the time of removal.

Head CT remains the most valuable imaging modality for initial evaluation of foreign objects and assessing the extent of injury, but may be of limited use in evaluating plastic or wood foreign objects. When there is a high index of suspicion for vascular injury, CTA at the very least, and preferably digital subtraction angiography (DSA), may be necessary before surgery for operative planning. In our case, 3DRA perspicuously showed the spatial relationship between the crossbow bolt and ACAs.

The rate of vascular complications after PBI reportedly ranges from 5 to 40%. TICA may present in a delayed fashion, with a mean presentation typically within 2–3 weeks after injury, but potentially months after injury. The most common vascular injury after PBI is development of pseudoaneurysm in peripheral vessels. TICA associated with PBI warrants aggressive management to prevent life-threatening complications, as the mortality rate from untreated TICA is reportedly as high as 50%. The present case showed no increase in aneurysm size during the first 2 weeks after PBI, but obvious changes were observed after a month. Follow-up CTA or DSA should therefore be performed until at least 4 weeks after injury.

TICA typically involves the vessels of the anterior circulation, the supraclinoid internal carotid artery, ACA, distal middle cerebral artery and middle meningeal artery. The prevalence of these aneurysms in the ACA is explained by the proximity of the falx to the arteries. Movement induced
by the injury can lead to stretching and shear injury of the vessel, with damage to the wall and aneurysm formation.\textsuperscript{14,16}\n
If the TICA bleeds or increases in size, surgical intervention is required. As the lesions are invariably pseudoaneurysms without true vascular layers, simple coil embolization of the outpouched sac may in fact precipitate hemorrhage. Similarly, clip ligation of the sac is inadequate. In many cases, the parent vessel may need to be sacrificed.\textsuperscript{13,17}\n
According to a review by Larson et al.,\textsuperscript{4} 15 of 37 aneurysms (40\%) were located in the ACA and its branches, most often in the pericallosal artery. Management options described in that report for ACA aneurysms varied from observation, invariably associated with poor outcomes (including death), to clipping and surgical excision, with endovascular coiling present later in the series. Kumar et al.\textsuperscript{6} reviewed the literature for traumatic ACA aneurysm, and dominance of the open surgical approach in early series and the recent increase and predominance of endovascular options can be clearly seen.

As the lesion was located in the peripheral vasculature, a balloon occlusion test could not be performed. The collateral circulation from the posterior cerebral arteries was therefore unable to be assessed. Considering the possibility of poor collateral flow, we decided to perform revascularization of the PIFA.

The present case required sacrifice of the PIFA, and good results were obtained with trapping and right PIFA-left cortical branch bypass. In the treatment of distal ACA traumatic pseudoaneurysm, trapping and right ACA-left ACA side-to-side bypass seems to represent a useful treatment option.

**Conclusion**

We encountered a case of pseudoaneurysm formation in the ACA after PBI caused by a crossbow bolt. Use of 3DRA proved helpful in confirming positional relationships between the bolt and the ACA. Continued follow-up with CTA or DSA for at least 4 weeks is recommended.

**Conflicts of Interest Disclosure**

The authors report no conflicts of interest (COI) concerning the materials or methods used in this study or the findings specified in this paper. All authors who are members of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

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